Active Thermal Control Experiments for LISA Ground Verification Testing

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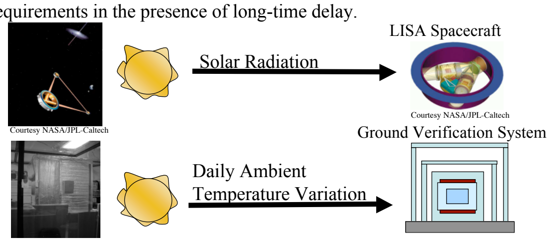
MOTIVATION & OBJECTIVE

•Thermal noise due to solar irradiation, or temperature gradients across the proof mass housing is expected to be significant disturbance source to the LISA noise budgets:

- •The total acceleration disturbances to each proof mass < 3×10^{-15} m/s^2 sqrt(Hz) over 0.1 mHz to 1 Hz
- •Optical path length variations on each optical bench < 40 pm/sqrt(Hz) over 0.1 mHz to 1 Hz

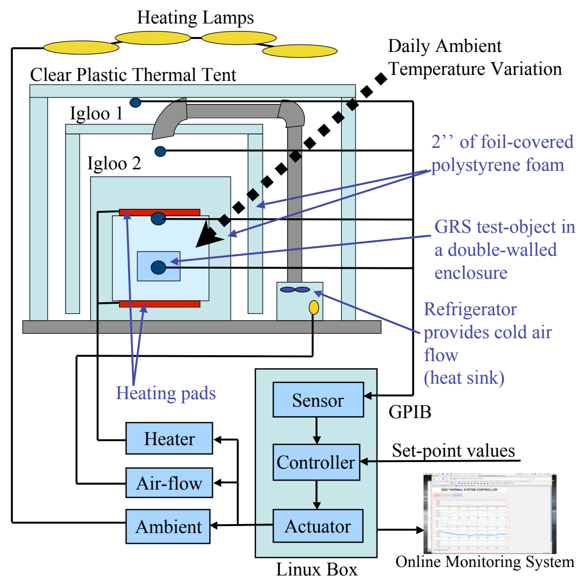
•A thermal control system is being developed for LISA GRS ground testing which could be used as in-flight thermal control of the LISA spacecraft to compensate solar irradiate 1/f fluctuations.

•For spacecraft the very limited thermal mass calls for an active control system which can simultaneously meet disturbance rejection and stability requirements in the presence of long-time delay.



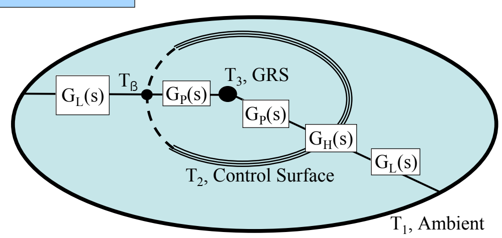
LISA Thermal Stability: 3×10^{-5} K/sqrt(Hz) for f > 0.01 mHz
- •Low frequency sinusoidal disturbance input
- •Time-delays

EXPERIMENTAL SYSTEM

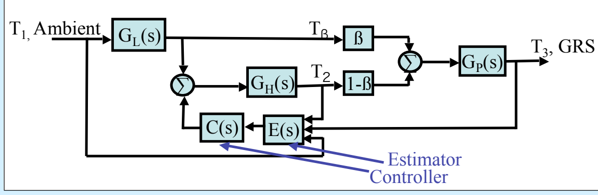


CONTROL SYSTEM DESIGN AND SYNTHESIS

First-order model



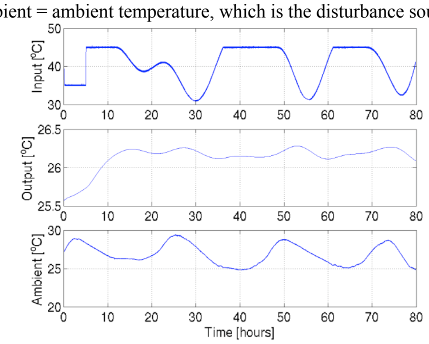
Feedback control block diagram of the entire system



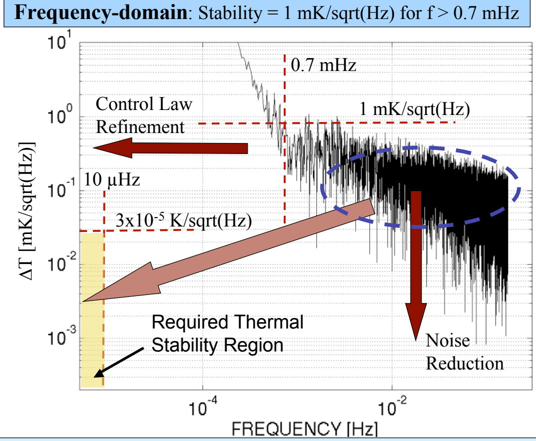
EXPERIMENTAL RESULTS

Time-domain: 80-hour test

•The control system (PI + Smith's regulator) is activated.
- •Input = heating pad temperature
- •Output = GRS test-object temperature
- •Ambient = ambient temperature, which is the disturbance source



Frequency-domain: Stability = 1 mK/sqrt(Hz) for f > 0.7 mHz



FUTURE WORK: Disturbance Rejection Control for Nonlinear MIMO Time-delay Systems

Nonlinear MIMO TDS

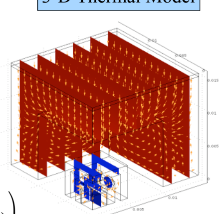
$$x(k+1) = f(x(k), u(k-\tau))$$
$$y(k) = g(x(k))$$

where
$$x(k) \in \Re^n, u(k) \in \Re^m$$

The controller minimizes the following cost function.

$$J = E\left(\sum_{k=0}^{\infty} x^T(k)Qx(k) + u^T(k)Ru(k)\right)$$

3-D Thermal Model



CONCLUDING REMARKS

•Suppressed the ambient temperature variations by a factor of 1,000 down to below 1 mHz using a simple control law and low-cost thermal insulations : 1 mK/sqrt(Hz) for f > 0.7 mHz

•To satisfy the LISA thermal stability requirements 1) measurement noise reduction and 2) control law refinement are necessary

•Next problem: regulating control for non-linear MIMO time-delay systems

Reference

[1] S. Higuchi, G. Allen, W. Bencze, R. Byer, A. Dang, D. Lauben, S. Dorlybounxou, J. Hanson, L. Ho, G. Huffman, F. Sabur, K. Sun, R. Tavernetti, L. Rolih, R. Van Patten, J. Wallace, S. Williams, "High-stability temperature control for ST-7/LISA Pathfinder gravitational reference sensor ground verification testing," *Journal of Physics: Conference Series*, 32:125-131, 2006.